SOHO ULTRAVIOLET CORONAGRAPH SPECTROMETER (UVCS) MISSION OPERATIONS AND DATA ANALYSIS

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FINAL REPORT

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1. INTRODUCTION

The scientific goal of UVCS is to obtain detailed empirical descriptions of the extended solar corona as it evolves over the solar cycle and to use these descriptions to identify and understand the physical processes responsible for coronal heating, solar wind acceleration, coronal mass ejections (CMEs), and the phenomena that establish the plasma properties of the solar wind as measured by "in situ" solar wind instruments.

This report covers the period from 01 December 2000 to 31 January 2002. During that time, UVCS observations have consisted of three types: 1) standard synoptic observations comprising, primarily, the H I Lyα line profile and the O VI 103.2 and 103.7 nm intensity over a range of heights from 1.5 to about 3.0 solar radii and covering 360 degrees about the sun, 2) sit and stare watches for CMEs, and 3) special observations designed by the UVCS Lead Observer of the Week for a specific scientific purpose. The special observations are often coordinated with those of other space-based and ground-based instruments and they often are part of SOHO joint observation programs and campaigns. Lead observers have included UVCS Co-Investigators, scientists from the solar physics community and several graduate and undergraduate level students.

UVCS has continued to achieve its purpose of using powerful spectroscopic diagnostic techniques to obtain a much more detailed description of coronal structures and dynamic phenomena than existed before the SOHO mission. The new descriptions of coronal mass ejections (CMEs) and coronal structures from UVCS have inspired a large number of theoretical studies aimed at identifying the physical processes responsible for CMEs and solar wind acceleration in coronal holes and streamers.

UVCS has proven to be a very stable instrument. Stellar observations have demonstrated its stability and the analysis of coordinated observations with Spartan 201 have verified the accuracy of the absolute calibration and spectral resolution at H I Lyα. UVCS has required no flight software modifications and all mechanisms are operational. The UVCS O VI Channel with its redundant optical path for wavelengths near H I Lyα is capable of observing the entire UVCS wavelength range. Since December 1998, the O VI Channel has been used for all UVCS observations. Although the H I Lyα Channel and detector are still operational, increases in the dark count up to about $5x10^{-4}$ counts/sec/pixel and an increase in high voltage current to within a factor of two of the maximum used in the laboratory before flight led to the decision to not use that detector at the present time. There is no significant decrease in the scientific capability of UVCS owing to the OVI channel redundant optical path.

UVCS data, data analysis software, calibration files and the mission log are available from the SOHO archive and SAO. The UVCS synoptic images of the extended corona are normally available to the public within 12 hours of the observation. As of 31 January 2002, all UVCS data were available to the general public through January 2001 as were the synoptic observing program data and sit and stare watches for CMEs. Special observations are released to the public one year after the observation date.

UVCS has resulted in 29, 24 and 45 published papers in 2000, 2001 and 2002, respectively. That is approximately 30 published papers during the period of performance of the subject grant. There were numerous presentations at scientific meetings. Over 48,000 UVCS data files have been requested from the SOHO archive by users throughout the world. All requests for observation time by qualified outside users have been granted.

2. HIGHLIGHTS OF UVCS OBSERVATIONS AND ANALYSES

The physical processes that heat the 10^6 K solar corona, accelerate the solar wind, and produce CMEs are still not known with certainty after more than a half century of investigation. UVCS has made significant progress toward identifying these processes by measuring densities, outflow speeds, anisotropic temperatures, and abundances in the acceleration region of the wind and CMEs.

Highlights: Coronal Holes and Fast Solar Wind

Plasma Properties of a High-Latitude Coronal Hole with the Next Solar Cycle Polarity: The resurgence of extreme ion properties in a large, high-latitude coronal hole above the north heliographic pole in 2001 February at solar maximum was observed (Miralles, Cranmer and Kohl, Ap. J., 560, L193, 2001). These observations are part of an ongoing campaign to determine the plasma properties of coronal holes during the current solar cycle. Comparison of the coronal line widths of the O VI doublet near 103nm showed that the O^{5+} perpendicular kinetic temperatures in the 2001 high-latitude hole are similar to those observed in polar coronal holes at solar minimum. These observations of extremely high ion kinetic temperatures exceeding $1x10^9$ K at the north pole in 2001 occurred nearly simultaneously with the polarity change of the Sun's magnetic field, as seen in recent magnetogram data. The coronal hole in 2001 may be the first manifestation of the negative polarity coronal holes that will dominate the Sun's open magnetic flux tubes at the next solar minimum.

Comparison of Empirical Models for Polar and Equatorial Coronal Holes: A self-consistent empirical model, which included several plasma parameters, of a large equatorial coronal hole observed by UVCS on 1999 November 12 near solar maximum was developed (Miralles et al., Ap. J., 549, L257, 2001). Comparison of its properties to that of a polar coronal hole observed in 1996 shows that the 1999 equatorial hole has lower O^{5+} outflow speeds and perpendicular temperatures than its polar counterpart at heights between 2 and 3 solar radii. However, asymptotic speeds of wind streams from these structures are similar. Thus, the bulk of the solar wind acceleration in the equatorial hole must occur above 3 solar radii. The equatorial hole also has a higher density than the polar hole at similar heights.

Ion Cyclotron Diffusion of Velocity Distributions in the Extended Solar Corona: UVCS has revealed strong kinetic anisotropies and extremely large perpendicular temperatures of heavy ions in the extended corona. These observations have revived interest in the idea

that the high-speed solar wind is heated and accelerated by the dissipation of ion cyclotron resonant Alfven waves. It was shown by Cranmer (J. Geophys. Res., 106, 24937, 2001) that this process naturally produces departures from Maxwellian and bi-Maxwellian velocity distributions. He argues that these departures must be taken into account in order to understand the resonant velocity-space diffusion, the wave damping, and the formation of ultraviolet emission lines. He concludes that waves propagating solely from the coronal base would not be able to heat and accelerate the ions that have been observed to exhibit strong energization, and that local wave generation is required.

Heating of Coronal Holes and Generation of the Solar Wind by Ion-Cyclotron Resonance:
A good example of the impact of UVCS observations and resulting empirical models on theoretical work is the review paper by Isenberg (Space Sci Rev., 95, 119, 2001). He describes a new model to explain the heating of the magnetically open solar corona and the acceleration of the fast solar wind by the cyclotron resonant interaction of coronal ions with ion-cyclotron waves. He shows that a fast solar wind can be generated by this process. Several properties of the resonant interaction as implied by the model are provided. The structure of the resonant shells for ions heavier than protons indicates that these ions will be perpendicularly heated by the second-order Fermi process, and energization channel that is not available to the protons. This last point is particularly intriguing, and may lead to a fundamentally new way to produce the preferential effects on heavy ions in the fast solar wind that are needed to explain the UVCS observations.

Highlights: Coronal Mass Ejections (CMEs)

Energy estimates and hydrodynamics of a helical CME:
UVCS spectra were used to investigate the density range of the plasma ejected during the CME of 1997 December 12 (Ciaravella, A.; Raymond, J. C.; Reale, F.; Strachan, L.; Peres, G., ApJ, 557, 351, 2001). Time-dependent ionization states for several phenomenological models, with the boundary conditions derived from EIT and UVCS observations, were computed and constraints on the density and temperature of the plasma at the early stage of the ejection were obtained. The role of physical mechanisms such as thermal conduction, radiation, and heating was also studied with a two-dimensional hydrodynamics simulation. The kinetic, thermal, and gravitational energies were estimated as well as the plasma heating. Whenever the ejected plasma has a density greater than or equal to 1×10^9 cm^{-3}, a continuous supply of heat is required to meet the conditions observed at 1.7 solar radii. Moreover heating mechanisms that release energy gradually during the outward motion of the plasma seem to be more appropriate than those that dump most of the energy when the plasma is lower in the corona. Simulations also indicate that a three-dimensional self-similar expansion does not fit the UVCS observations.

The morphology of a CME, and a description of its plasma parameters:
Joint observations of a CME on 1999 April 23 by UVCS, EIT, and LASCO (Akmal, A.; Raymond, J. C.; Vourlidas, A.; Thompson, B.; Ciaravella, A.; Ko, Y.-K.; Uzzo, M.; Wu, R. Ap J, 553, 922, 2001) were used to obtain an unusually complete description of a CME event. In addition to the O VI and C III lines typical of UVCS spectra of CMEs, this 480 km s^{-1} CME exhibited the forbidden and intercombination lines of O V at 121.38 and 121.84nm. The relative intensities of the O V lines permit an accurate electron density diagnostic not generally available at 3.5 R_{sun}. By combining the density with the column density derived from LASCO, the emission measure of the ejected gas was derived. With the help of models of the temperature and the time-dependent ionization state of the expanding gas, a range of heating rates required to account for the UV emission lines were also derived. The total thermal energy deposited as the gas travels to 3.5 R_{sun} is comparable to the kinetic and gravitational potential energies. The analysis indicated a core of colder material radiating in C III, surrounded by hotter material radiating in the O V and O VI lines. This concentration of the coolest material into small regions may be a common feature of CMEs.

3. UVCS/SOHO EDUCATION AND PUBLIC OUTREACH ACTIVITIES

UVCS scientists are involved in numerous education and public outreach activities that are used to both inform popular audiences about the findings of *SOHO* research and to enrich science classroom activities for teachers and students. These activities range from making appearances on local TV stations, presenting a NASA Space Science Update, engaging the public at special events like Astronomy Day, and distributing *SOHO* educational materials (posters, stickers, and CD-ROMs). One UVCS Co-I (L. Strachan) answers questions received at the "Ask Dr. Soho" Web Site. On average he answers 1 to 2 questions per week from students, teachers, and the public.

SOHO 5th Year Anniversary and Sun-Earth Days 2001: Ten UVCS scientists and collaborators gave presentations for the *SOHO* 5th Year Anniversary Celebrations and Sun-Earth Days. The talks were located at science museums, a planetarium, high schools, colleges, and an elementary school. Some of the talks were given in Spanish or Italian in addition to English for reaching out to diverse audiences. Thousands of people attended these events and many tens of thousands more were reached in a radio broadcast of one of the events.

SAO-Southern University Partnership: L. Strachan, J. Kohl, S. Cranmer, J. Raymond, and R. Suleiman are involved in a pilot program to introduce solar science topics to minority students at Southern University in Louisiana. The project involves making guest lectures at Southern, providing student summer research projects, and mentoring to students. This program has a long-term goal of building a research infrastructure at minority institutions so that these schools can compete for NASA research programs.

4. SOFTWARE, COMMANDING, AND TELEMETRY

UVCS makes extensive use of observation sequences stored in on-board memory. These consist of multiple instrument commands with various parameter sets. A particular sequence and parameter set is selected by an uploaded command. Recent commanding sessions for UVCS last about 1 hour and typically occur once per day. Intensive commanding sessions occur from time to time for special observations. More than 170 commands per day, on average are sent.

UVCS losses due to instrument problems such as software resets or reconfigurations remain at about 1 day per month on average. Ground/DSN problems affect the quality of the data received, but are negligible except for rare occasions.

There have been no patches to UVCS flight software to date, and none are planned or needed.

5. UVCS INSTRUMENT STATUS

UVCS is expected to continue performing at full scientific capability for many more years. Star observations and coordinated observations with *Spartan* 201 are used to track the UVCS radiometric calibration, which has remained remarkably stable. The absolute radiometric calibration in the primary wavelength ranges is believed to be know to within ± 20% which is sufficient for all proposed observations. No flight software changes have been needed. All mechanisms are performing nominally except the Lyα channel grating drive which continues to degrade; use is restricted, but scientific function is redundantly provided by the O VI channel grating drive and a redundant optical path that is used to observe wavelengths near H I Lyα. That path is also used to observe spectral lines in second order such as Mg X, Si XII, and several others. The second order calibration is known to about ± 50%. Spectral and spatial resolutions, the wavelength scale, flat field variations, the pointing and absolute spatial scale, and stray light levels are stable and well characterized. The number of operations for all mechanisms is within design limits. Instrument operational temperatures are expected to remain within acceptable ranges. The UVCS XDL detector for the O VI channel is performing well. There is no significant degradation to the efficiency except on about 20% of the photosensitive area which is used to detect Lyα. Incremental increases in high voltage are used to maintain the efficiency for the Lyα portion to within 5% loss. Voltage increases of 5 EU every 1.2 years is expected to keep efficiency loss at <5%. The high voltage for the Lyα channel XDL detector has been turned off since November 1998 because it draws about 50% of the maximum tested high voltage current and because it has regions of elevated background up to X5. This detector is still operational and is treated as a back-up detector for Lyα observations.

6. ANOMALIES

There have been no hardware components lost and no intermittent failures.

UVCS has detected one single event upset since the beginning of mission. It occurred on 12 April 1998 and triggered the watchdog timer.

7. INSTRUMENT GROUND SOFTWARE

The UVCS Mission Operations Software developed by SAO and used for UVCS commanding has functioned flawlessly throughout the operations phase of the mission. There have been no significant updates and none have been needed.

8. DATA PROCESSING AND ARCHIVING

Processing of SOHO level zero telemetry is reformatted and converted to FITS files almost immediately at the EOF to monitor instrument health and function during all NRT periods. It is also made available to the Lead Observer and Operations Team on the day following an observation to determine the success of the observation. The UVCS Lyα and OVI synoptic and composite images are normally made public within 12 hours. Level zero data on CD is also sent to the Smithsonian Astrophysical Observatory where it is reformatted to Level 1 FITS files within two days of receipt.

The UVCS synoptic data sets and sit and stare watches for CMEs are made available from the SOHO archive and SAO within one month of receipt of CD ROM telemetry data from NASA. The special observations data are made public and put on the SOHO archive one year after the observation date. UVCS distributions of level 1 data include calibration files and data analysis software.

A complete set of Level 1 data plus backups exists at the Smithsonian Astrophysical Observatory. This archive also includes calibration files, data analysis software and mission logs.

Currently through the UVCS Web Site, one can find a list of observations planned and completed, a list of all published papers and abstracts by UVCS scientists and guest investigators, the UVCS data analysis software and calibration files, a tutorial on using the UVCS data and the analysis tools including a coronal model code and a user's guide. Also the mission logs are available on the web site in a user friendly search engine.